THE UNIVERSITY OF TEXAS AT AUSTIN

REPORT ON THE

LUNAR RANGING

at

MCDONALD OBSERVATORY

FOR THE PERIOD

DECEMBER 6, 1972 TO MARCH 5, 1973*

by

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and

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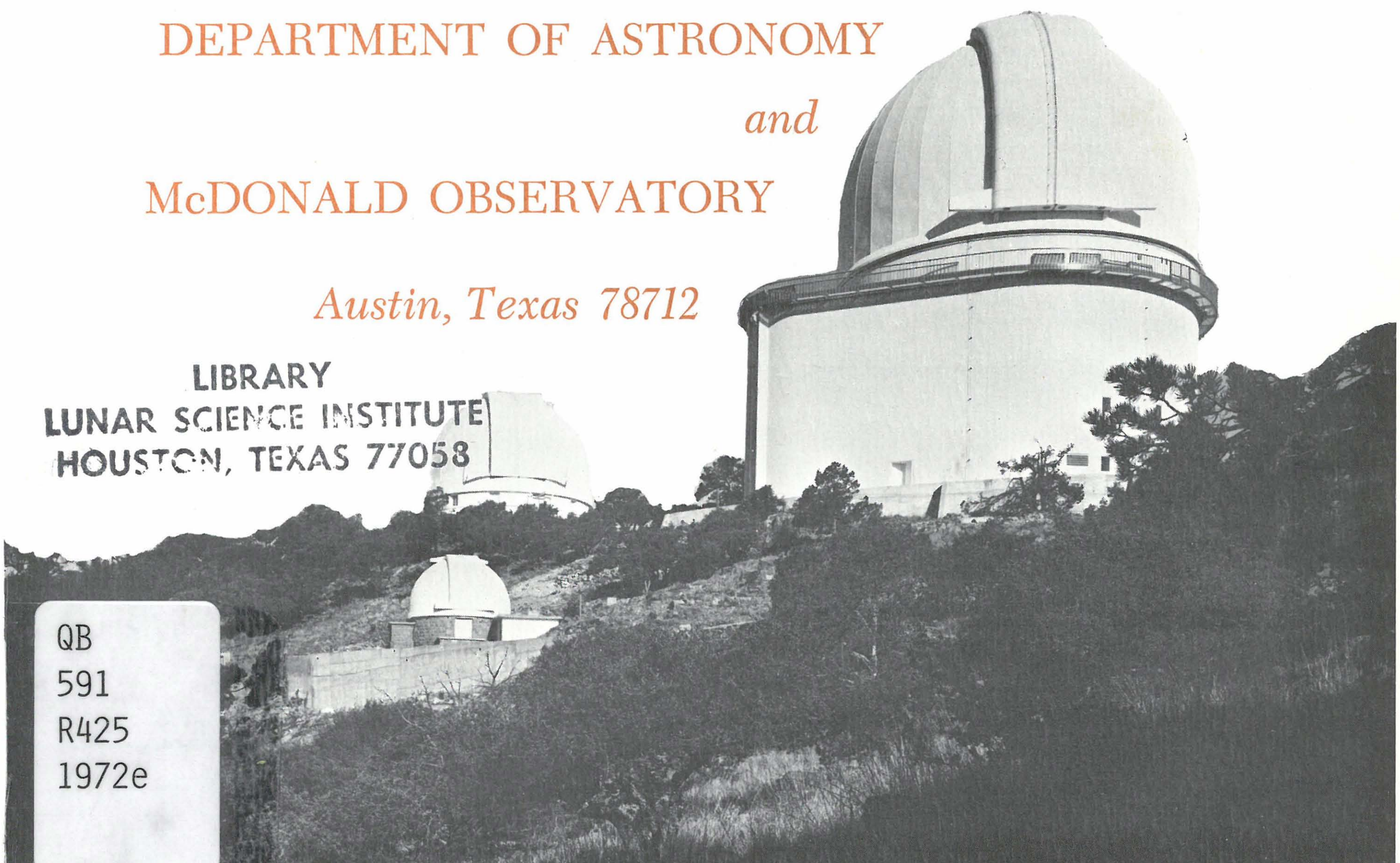

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Research Memorandum in Astronomy #73-003

March 1973

* This work is supported by NASA Grant NGR 44-012-165

ABSTRACT

Reasonably good data rates were maintained on the three Apollo reflectors throughout the quarter covered by this report. In addition, six range measurements were made on the French reflector array carried on an unmanned Soviet lander. System modifications were limited to a few small changes in operation designed to increase the average signal level.

TABLE OF CONTENTS

I. OPERATIONS DURING THE QUARTER

The three lunations described in this report represent the first full quarter of operation following the installation of the spur gear system on the 107" telescope. As the quarter began some problems were still encountered in both the pointing and tracking functions of the instrument. Most of these were corrected during the new moon period following the December lunation permitting the experiment to operate at nearly full efficiency for the last two months. The result was a total of 79 lunar range measurements out of 100 attempts. Most of the measurements were of good quality reflecting excellent signal levels. The overall measurement accuracy throughout the period lay between 10 to 25 centimeters. One measure of the good signal levels is shown by the fact that the laser crew was able to make 22 of the lunar range measurements using 100 laser shots or less. Measurements at three spaced hour angles on at least one of the corner reflectors were made on seven days during the quarter. Table I summarizes the performance on each of the four corner reflector arrays. As usual, the log sheets showing the day by day operations of the experiment are included as Appendix I.

The highlight of the last quarter was the acquisition of the corner reflector carried by Luna 21. Aided by Derral Mulholland of the University of Texas at Austin, as well as A. Orzag and O. Calame of the Ecole Polytechnic, the laser crew was able to locate the French corner reflector on January 23rd, the second day of attempts. The signal levels acquired from the corner reflector appeared excellent, in as much as the returns were possible with the beam diverged to 7 arc seconds. The following night the laser crew was unable to reacquire the corner reflector with a slightly longer offset guiding position. (It was later found that the calculated offsets used on the second night were wrong, either due to guider field curvature or an incorrect scale factor.)

Weather restrictions did not permit laser ranging to the French/Soviet corner reflector during the first quarter of the February lunation. Thus, it was not possible to uniquely determine the position of the reflector before the first traverse of the surface which would be attempted by the Soviets on that lunar day. Since the previous corner reflector, landed by Luna 17, appeared to be degraded by the motion of the Lunokhod, we retained an extremely pessimistic outlook. Fortunately, however, we were able to reacquire the corner reflector early on February 24 with little if any apparent loss of signal. Three ranges were measured on that day at very widely spaced hour angles and an additional range was added on February 25 before the field of the coude guider was exceeded. The three days measurements coupled with some knowledge of the motion of the reflector during the lunar day should permit a much better understanding of the location than possible by any other means. In as much as the Lunokhod corner did not appear to degrade noticeably between the January and February lunations, it would seem to be a hopeful sign that many more ranges can be acquired from the roving corner during the coming months.

TABLE I

SUMMARY OF OBSERVED SIGNAL LEVELS

	Number of Laser Shots	Number of Returns	Average Signal
Apollo 11 LRRR	3164	88	.028 P/S
Apollo 14 LRRR	2242	97	.043
Apollo 15 LRRR	10418	517	.050
Lunokhod II	4011	64	.016
All Corners	19835	766	.038 P/S

II. TECHNICAL COMMENTS

A) Guiding

Throughout the quarter the laser experiment relied entirely on offset guiding with the x-y stage in the laser room. Although some improvements are still possible with this method the obvious result has been the acquisition of better signals in the dark moon phases and better coverage of lunar orbit near the new moon period. The guiding method was undoubtedly responsible for much better effort which we were able to put towards acquiring the Lunokhod II corner as opposed to the guiding methods used on Lunokhod I. The field of the offset guider makes it always possible to reach the Apollo 15 corner reflector from an illuminated limb as well as at least one of the other Apollo reflectors. The Lunokhod II corner can be accessed at anytime during the first quarter, and for three or four days following the terminator crossing in the third quarter.

B) Accuracy Versus Signal Strength

For some months the experiment has relied on a feedback calibration system both to monitor the high gain RCA 31000 F photomultiplier as well as the galium arsenide cathode tube. Unfortunately, in order to use the feedback system with the latter it was necessary to run the 31034 far above normal operating voltages, resulting in severe limitation on the maximum count rate which could be allowed in the tube. The count limitation did not allow us to use the higher transmission 3Å filter on any lunar phase except dark moon. Furthermore, the galium arsenide tube appears to have more intrinsic jitter than the high gain tube.

For some applications the inconveniences of the galium arsenide tube are more than balanced by the fact that the cathode sensitivity is about twice that of the conventional photomultiplier which we have as our first option. During the January lunation the laser operators switched back and forth between the two tubes and two filters trying to take advantage of both methods during the various lunar phases. The 31000 F system was calibrated using the feedback system as has been the usual method for the past several months. The 31034 was monitored by means of the pulser calibration which was then tied to the feedback calibration by means of pulser measurements taken with the other system. During the February lunation the system was kept entirely in the high signal mode, i.e. with the 31034 using the pulser calibration.

Using the 31034 and the .7Å filter the laser experiment can operate with a receiver efficiency of approximately 0.6%. Using the 3Å filter it is possible to have a receiver efficiency of approximately 1%. The figures for the 31000 F are approximately a factor of 2 lower. Thus, we are faced with a choice of sacrificing some accuracy in order to operate with the maximum signal levels. On the data cards which were issued during the last quarter, we have listed those system calibrations which relied solely on the light pulser measurements as having D quality; that is, an accuracy of about ± 1 nanosecond. The lower accuracy of the calibration is offset in many cases by the fact that the high gain tube allowed us to acquire a greater number of photoelectrons and thus reduce the statistical error due to the pulse width averaging. We should also point out, however, that despite the fact that the systematic offset on any one day is known with poorer accuracy, relative delays between the laser runs on any one day are still as consistent as when the feedback calibration had been used. Thus, for some aspects of the analysis problem, the highest signal mode may, in fact, result in greater accuracy than if the lower signal and feedback calibration had been used. We will continue to switch back and forth between the various PMT and filter options in the next few months until the needs of the project require that the high accuracy mode of operation shall predominate.

C) Possible System Malfunctions

As yet we have not found it necessary to issue any amendments to the data cards issued during the last quarter. We do, however, suspect that a small percentage of the data, especially during the latter part of the quarter, was affected by a so-called 50 nanosecond jump. It appears that the ranging system occasionally counts an extra clock pulse, thus resulting in returns which are an integral number of 50 nanoseconds higher than the true result. We have not been able to reproduce this malfunction in test runs. Thus, we have no information as to what percentage of the data is likely to be affected.

D) T. V. Guiding System

During the last quarter J. Wiant has been able to produce a prototype of what we hope will be a television-like viewing for the guide station. The purpose of this development work is to provide both a higher contrast image during the near new moon period, for the purposes of crater recognition, as well as an automatic guiding feature for the 107" during the illuminated portion of the lunar cycle. Working in cooperation with the planetary astronomers, who have similar interests, we have run some elementary tests with a silicon diode array in both laboratory and observing conditions. The results look hopeful but some basic problems will still need to be overcome.

The early tests with the diode array indicate that the system will be able to sense a 1% change in brightness with little difficulty. This is somewhat superior to the human capability for the near new moon work. The sensitivity of the device is such that it can reliably detect about 15,000 photons per integration time. In order to produce the required contrast it probably will be necessary to integrate for about 25 ms on the daytime lunar image before readout onto a CRT. Further information will have to await the tests which we have scheduled for first quarter in March. If those prove successful we will proceed with a working version of the diode array during the next few months.

E) Hawaii Station Help

A conversation with W. Carter of the University of Hawaii indicated that little work had been done on the calculation of the lunar position for use by the Hawaii telescopes. In order to provide the on-site flexibility that we enjoy at McDonald, it was decided to attempt to write a program similar to that used in our IBM 1800 computer. F. Hudson determined that the task was possible and has proceeded to recode our program into machine language suitable for the Nova used on the fly's eye receiver. While the total effort required was not small and totaled several man weeks, this was still probably a factor of four faster than attempting the task with someone not intimately familiar with the problem. Sometime during the next quarter, as mutual schedules permit, Hudson will be sent to Boulder to assemble and debug the pointing program using the fly's eye Nova.

In addition to the before mentioned effort, Hudson spent almost two man weeks with the Hawaii programmer during the month of January. It was later felt that the visit was very profitable since they were able to outline many of the tasks which the Maui personnel will have to duplicate in their software.

APPENDIX I

DAILY OPERATING LOG

DECEMBER 6, 1973 TO MARCH 5, 1973

STATION LOG, DECEMBER 1972

DATE	TIME	RUN NO.	NO. OF SHOTS	RETURNS	WEATHER	SEEING	COMMENTS
Dec. 10	01:45-04:45-07:45				cloudy		runs cancelled
Dec. 11	02:30-05:30-08:30				cloudy		runs cancelled
Dec. 12	03:30	(478)	150/0	0/0	clear	4	Laser electronics down after 150 shots
	06:30				cloudy		cloudy laser electronics down
	09;30				clear		Laser electronics down
Dec. 13	04:30-07:30-10:30				clear		Laser electronics down
Dec. 14	05;00-08:00-11:00				clear	6-8	used for pointing tests
Dec. 15	05:30				Ptly. cloudy		Repaired Laser
	08:30				clear		Telescope pointing problems
	11:30	(479)	375/3	0/3	clear	5	
Dec. 16	06:30				cloudly		
	09:30	(480)	145/3	10/3	clear	3	
		(481)	200/2	10/2	clear	3	
		(482)	150/0	9/0	clear	3	
	00:30	(483)	150/3	11/3	clear	3	
		(484)	25/0	0/0	clear	3	TDG problems
Dec. 17	19:10	(485)	250/3	17/3	clear	3	12 in last 50 shots
		(486)	100/2	6/2	clear	3	
	22:15	(487)	285/3	6/3	cirrus	6-7	Image motion
	01:15	(488)	210/3	8/3	lt. cirrus	6	Image motion
Dec. 18	20:00				cloudy		
	23:30	(489)	120/3	14/3	Ptly. cloudy	3-4	
		(490)	100/2	12/2	" "	"	
		(491)	200/0	6/0	" "	"	
	02:00	(492)	250/3	5/3	" "	4-5	Telescope tracking poor
		(493)	150/2	0/2	" "	"	" " "
Dec. 19	21:00	(494)	280/3	11/3	clear	3-4	Image Motion
	01:30	(495)	315/3	8/3	clear	"	" " wind
		(496)	150/2	4/2	"	"	" " "
Dec. 20	23:00-02:00				clear	7-8	Bad Seeing

STATION LOG, DECEMBER 1972

DATE	TIME	RUN NO.	NO. OF SHOTS	RETURNS	WEATHER	SEEING	COMMENTS
Dec. 22	00:00-04:00				clear	7-8	Bad Seeing TDG Problems
Dec. 23	01:30-04:30				clear		blowing wind
Dec. 24	01:55	(497)	272/3	0/3	clear	4	Telescope tracking very poor
	05:30	(498)	278/3	9/3	"	2	mostly wrong delta
		(499)	335/0	0/0	"	"	
Dec. 25	03:00-06:00				cloudy		Runs cancelled
Dec. 26	03:30-07:00				clear	7-8	Bad seeing
Dec. 27	04:00	(500)	237/3	10/3	clear	3	
		(501)	143/2	4/2	clear	"	
	08:00	(502)	87/3	0/3	Lgt. cirrus	3	Stopped by clouds
Dec. 28	04:45-08:45				cloudy		Runs cancelled
Dec. 29	06:00	(503)	227/3	0/3	clear	4	
	08:00	(504)	187/3	3/3	clear	4	Bad contrast at last of run
Dec. 30	06:00-09:00				clear		windy
Dec. 31	07:00-09:30				Clear	6-8	Bad seeing

TOTALS FOR DECEMBER	TRIES	SUCCESSFUL RANGE MEASUREMENTS
	5/0	2/0
	6/2	5/2
	16/3	12/3

STATION LOG, JANUARY 1973

DATE	TIME	RUN NO.	NO. OF SHOTS	RETURNS	WEATHER	SEEING	COMMENTS
Jan. 9	14:00				cloudy		
	17:00				cloudy		
	20:00				cloudy		
Jan. 10	14:45						
	17:45						
	20:45				snow		
Jan.11	15:30				clear		focus troubles
	19:00	(1)	297/3	0/3	clear	4	
	21:30	(2)	285/3	6/3	clear	3	
Jan. 12	17:00	(3)	50/3	10/3	clear	3	
		(4)	142/0	0/0	clear	3	
		(5)	187/2	0/2	clear	3	
	20:00	(6)	304/3	4/3	clear	4	
	22:00	(7)	277/3	7/3	clear	4	
Jan. 13	17:00	(8)	125/3	15/3	clear	2	
		(9)	166/2	7/2	clear	2	
		(10)	96/0	6/0	clear	2	
	21:00	(11)	43/3	9/3	clear	1	rushed by telescope
		(12)	48/2	11/2	clear	1	breakdown during run
		(13)	92/0	13/0	clear	1	
	23:30	(14)	50/3	12/3	clear	1	
		(15)	182/2	6/2	clear	1	inexplicably low signal
		(16)	138/0	3/0	clear	1	possibly wrong focus
Jan. 14	18:00	(17)	46/3	11/3	clear	2	3.0A filter with polarizer
		(18)	135/2	11/2	clear	2	3.0A filter w/o polarizer
		(19)	132/0	5/0	clear	2	0.7A filter
	21:00	(20)	47/3	15/3	clear	2	3.0A filter with polerizer
		(21)	229/0	14/0	clear	2	
	00:00	(22)	91/3	19/3	clear	2	
		(23)	34/0	0/0	claer	2	laser flashlamp trouble
Jan. 15	18:30				cloudy		
	21:30				"		
	00:30				"		
Jan. 16	19:30	(24)	259/3	18/3	clear	2	Experimented with filters
	23:45	(25)	87/3	12/3	clear	2	

STATION LOG, JANUARY 1973

LATE	TIME	RUN NO.	NO. OF SHOTS	RETURNS	WEATHER	SEEING	COMMENTS
Jan. 16	23:45	(26)	247/0	4/0	cirrus	2	stopped by clouds
	02:30	(27)	306/3	0/3	cirrus	2	clouds, wind
Jan. 17	20:30				cloudy		
	01:30				cloudy		
	03:30				cloudy		
Jan. 18	20:30	(28)	97/3	10/3	clear	1	
		(29)	239/0	4/0	clear	1	
		(30)	66/3	0/3	clear	1	
	02:00	(31)	150/3	9/3	clear	2	
		(32)	280/0	0/0	clear	2	
	04:30	(33)	241/3	5/3	clear	3	cirrus
Jan. 19	23:45	(34)	83/3	9/3	clear	2	light haze
		(35)	292/2	0/2	clear	2	" "
	02:45	(36)	200/3	9/3	cirrus	2-3	
	05:45				cloudy		
Jan. 21	00:00				cloudy		
	05:30				cloudy		
Jan. 22	00:45				cloudy		laser heater trouble
	06:30				cloudy		" " "
Jan.23	02:00				cloudy		
	08:30				cloudy		
Jan. 24	03:00	(37)	228/3	11/3	clear	3	
		(38)	681/4	0/4	clear	3	
	07:00	(39)	478/4	0/4	partly cloudy	3	
Jan. 25	03:00	(40)	412/4	13/4	clear	2	
		(41)	243/3	5/3	clear	3	
		(42)	142/4	5/4	clear	3	
Jan. 26	04:30	(43)	193/3	6/3	clear	2	image motion
		(44)	648/4	0/4	clear	2	" "
	08:00	(45)	190/3	0/3	clear	3	poor contrast,image motion
Jan. 27	05:00				cloudy		
	10:00				"		

STATION LOG, JANUARY 1973

DATE	TIME	RUN NO.	NO. OF SHOTS	RETURNS	WEATHER	SEEING	COMMENTS
Jan. 28	06:00				cirrus	8	cancelled, bad seeing
	09:00	(46)	386/3	5/3	clear	4	
Jan. 29	07:00	(47)	241/3	0/3	clear	3	
	10:00				cloudy		
Jan. 30	07:30				cloudy		
	10:30				"		
Jan. 31	08:00				cloudy		
	11:00				cloudy		

TOTALS FOR JANUARY	TRIES	SUCCESSFUL RANGE MEASUREMENTS
	10/0	7/0
	6/2	4/2
	26/3	22/3
	5/4	2/4

STATION LOG, FEBRUARY 1973

DATE	TIME	RUN NO.	NO. OF SHOTS	RETURNS	WEATHER	SEEING	COMMENTS
Feb. 6	13:00				cloudy		clouds, cancelled
	16:00				cloudy		" "
	19:00				cloudy		" "
Feb. 7	14:00				cloudy		" "
	17:00				cloudy		" "
	20:00				cloudy		" "
Feb. 8	14:45				cloudy		" "
	17:45				cloudy		" "
	20:45				cloudy		" "
Feb. 9	15:00				cloudy		" "
	18:00				cirrus	7-8	net on A. Tau 10K
	21:30	(48)	140/0	0/0	clear	6-8	
		(49)	366/4	0/4	clear	4-6	
Feb. 10	16:00				cloudy		run cancelled
	19:00				cloudy		" "
	22:00				cloudy		" "
Feb. 11	18:00				cloudy		cloudy
	21:00				cloudy		"
	24:00				cloudy		"
Feb. 12	19:00	(50)	125/3	15/3	clear	2	
		(51)	105/0	9/0	clear	2	
		(52)	92/2	12/2	clear	2	excellent night
	22:00	(53)	47/3	13/3	light cirrus	1	
	01:00	(54)	49/3	11/3	clear	1	
Feb. 13	20:00	(55)	62/3	12/3	clear	4	
		(56)	239/0	6/0	cirrus	4	
	23:00				cirrus		clouds, fog
	02:00				cirrus		" "
Feb. 14	21:15	(57)	192/3	45/3	clear	3	experiments w/polariser
	00:15	(58)	141/3	16/3	clear	3	" " "
	03:15	(59)	143/3	21/3	cirrus	2	" " "
Feb. 15	22:00	(60)	48/3	12/3	clear	3	
		(61)	191/0	4/0(?)	clear	4	
	01:00				cloudy		fog, clouds
	04:00				cloudy		fog, cloudys

STATION LOG, FEBRUARY 1973

DATE	TIME	RUN NO.	NO. OF SHOTS	RETURNS	WEATHER	SEEING	COMMENTS
Feb. 16	23:00				cloudy	5	clouds, (A. Tau, net 50)
	02:00				fog		clouds
	04:00				fog		clouds
Feb. 18	23:30				fog		cancelled
	03:00	(62)	128/3	10/3	clear	4-6	
	06:00	(63)	332/3	6/3	clear	5	
Feb. 19	00:30				cloudy	3	cancelled
	03:30	(64)	281/3	7/3	cirrus	5	
	06:30				cirrus	7	cancelled
Feb. 20	00:00				cloudy		"
	03:00				cloudy		"
	06:00				cloudy		"
Feb. 21	00:30				fog		"
	03:30				fog		"
	06:30				fog		"
Feb. 22	01:30				snow		"
	04:30				snow		"
	07:30				snow		"
Feb. 23	02:30				cloudy		"
	05:30				cloudy		"
	08:30				cloudy		"
Feb. 24	05:00	(65)	547/4	21/4	clear	7	repaired laser choke
		(66)	140/3	6/3	clear	5	
		(67)	96/4	7/4	clear	5	
	09:00	(68)	220/4	6/4	clear	6	
Feb. 25	05:00				cloudy		
	08:00	(69)	229/4	7/4	ptly. cloudy	2	difocussed to 5
	10:00	(70)	179/3	10/3	ptly. cloudy	2	7 in last 40
		(71)	192/2	4/2(?)	ptly. cloudy	2	
		(72)	192/4	0/4	ptly. cloudy	2	
Feb. 26	05:00	(73)	105/2	10/2	clear	2	
		(74)	93/3	10/3	clear	2	
	08:00	(75)	175/3	11/3	clear	2	

STATION LOG, FEBRUARY 1973

DATE	TIME	RUN NO.	NO. OF SHOTS	RETURNS	WEATHER	SEEING	COMMENTS
Feb. 27	06:00	(76)	30/3	0/3	clear	2	laser breakdown
	09:00				cloudy		laser breakdown
Feb. 28	07:00				cloudy		cancelled
	10:00				cloudy		"
Mar. 1	07:45				windy		"
	10:00				windy		"
Mar. 2-Mar. 7		New Moon Break					

TOTALS FOR FEBRUARY	ATTEMPTS	SUCCESSFUL RANGE MEASUREMENTS
	4/0	3/0
	4/2	3/2
	16/3	15/3
	5/4	4/4

TOTALS FOR QUARTER	ATTEMPTS	SUCCESSFUL RANGE MEASUREMENTS
	19/0	12/0
	16/2	12/2
	55/3	49/3
	10/4	6/4

APPENDIX II

SYSTEM CALIBRATION DATA

SYSTEM CALIBRATION DATA

The following pages contain the calibration constants for the quarterly period covered by the present report. The catagories A through E are explained below.

A - This column contains the uncorrected calibration constant for the entire lunar ranging system as measured by a light emitting diode. It is approximately 5.5 nanoseconds higher than the final calibration value due to internal delays in the photodiode as well as geometric corrections.

B - This column shows the results of calibrating only the relative delays between the photodiode and photomultiplier sides of the ranging system using a separate time-to-pulse height converter and a pulse height analyzer.

C - This column gives the arithmetic mean of the feedback calibration return through the entire lunar ranging system as recorded during the actual lunar ranging by the system teletype.

D - This column shows results of subtracting the 2.9 nanosecond geometric correction from Column C. The units have been changed to tenths of nanoseconds and a minus sign added to coincide with how this additive constant appears on the preliminary data cards. Letters A, B, C, and D follow the corrected calibration constant to indicate the relative accuracy, where: A = $\pm$ 200 picoseconds; B = $\pm$ 400 picoseconds; C = $\pm$ 600 picoseconds; and D = $\pm$ 1200 picoseconds.

December Calibration Data

Date	A	B	C	D
December 11 (347) C 31000F 2700 V G = 0, D = 100 short delay	10.7	(+30) -	-	-30E
December 16 (351) 31000F 2600 V, Int = 10 G = 10, F = 0.2 D = 100	13.7	32.4	?	-60E
December 17 (352) 31000F G = 10, I = 10 D = 170, 2600V	14.2	34.5	13.0D?	-60D
December 18 (353)	-	-	-	-60D
December 18 (354)	21.1?	34.4	8.1A	-52B
December 20 (355)	19.6?	35.0	9.3A	-64B
December 24 (359)	12.42	32.0	8.1B	-52C
December 27 (362)	11.1	35.0	-	-52C
December 28 (363)	11.8	-	-	
December 29 (364)	11.7	35.0	-	-52D

January Calibration Data

Date	A	B	C	D
January 9 C 31000F, G = 10 int = 10, D = 50 DIS = 1 delayed start	12.9	-	-	-
January 11	12.6	-	-	-59C
January 12	-	32.3	8.8A	-59B
January 13	12.7	32.8	8.9B	-60B
January 14	12.3	33.4	8.5C	-56B
January 17	12.3	31.1 double	6.6 double (fiber)	-56C
January 19	12.3	32.4	8.5B	-56B
January 20	12.3	none	8.9A	-60B
January 21	12.3	-	-	-
January 21 (20 GMT) GaAs tube, G = 200 Disc = 100; All else same	3.3D	-	-	+30D
January 22 GaAs, 1800V G = 200	4.9D	-	-	+14D
January 25	4.1D	-	-	+22D
January 26	4.0D	24.9	-	+23D
January 28	3.9	-	-	+24D
January 29	4.6	-	-	+17D

February Calibration Data

Date	A	B	C	D
GaAs tube, 1800V G = 200, D = 100 DIFF = 50, Int = 10				
February 9 (041)	4.5	-	-	22D
February 10 (042)	3.5	-	-	32D
February 11 (043)	5.2	-	-	15D
February 12 (044)	5.7	-	-	10D
February 13 (045) changed delay	14.6	-	-	-72D
February 15 (046)	11.9	-	-	-60D
February 16 (047)	13.2	-	-	-65D
February 17 (048)	12.4	-	-	-57D
February 18 (049)	13.5	-	-	-68D
February 19 (050)	12.5	-	-	-58D
February 20 (051)	13.1	-	-	-64D
February 21 (052)	10.7	-	-	-52D
February 22 (053)	13.8	-	-	-71D
February 23 (054)	12.5	-	-	-58D
February 24 (055)	11.4	-	-	-47D
February 25 (056)	13.5	-	-	-68D
February 26 (057)	12.5	-	-	-57D
February 27 (058)	12.6	-	-	-57D